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ROOT AERATION AND STEM GROWTH

A recent paper* by F. W. Went from the California Institute of Technology sheds new light on the important subject of root aeration and suggests a fruitful line of investigation to be applied to horticultural technique.

In the experiments first described, young tomato plants were grown in sand. When they had reached a length of 10 to 15 cm. the root system was washed free of the adhering sand, and the stem below the cotyledons was split lengthwise so that on one plant two separate root systems were obtained, each attached to one half of the stem base. After two weeks in aerated nutrient solution the root systems were well developed, and the two halves could be subjected to different conditions in an attempt to separate various functions.

It was found that if all the roots were submerged in a nutrient solution of pH 6 or higher, chlorosis developed in the tomato plants and the growth rate of the stems dropped, although root growth was satisfactory. Aeration of the solution, even when abundant, did not prevent these effects; but as soon as a portion of the root-system was allowed to develop on some well-aerated, moist, solid medium such as peat, haydite, silica gravel or glass wool, chlorosis disappeared and growth of the stem increased.

In further experiments, instead of mechanically dividing the root-system into two parts, tomato plants were induced to develop a root system outside the nutrient solution in addition to the roots in the nutrient. This was done by growing them in wire baskets, containing a layer of about 3 cm. of peat, haydite, gravel, sand or soil kept wet with tap water. These baskets were suspended from the edge of two-gallon crocks, two-thirds filled with nutrient solution which was well aerated. The stems of tomatoes, germinated in sand and transplanted into the baskets, extended through the wire basket so that all roots dipped into the nutrient solution, and within two weeks from planting a second root system developed in the medium in the basket.

Under these conditions the tomatoes grew slowly until the roots in the basket were well developed, then their growth increased to approxi-

*Effect of the root system on tomato stem growth—*Plant Physiology* Vol. 18 No. 1, pp. 51-65, January, 1943.

mately the same rate as that of tomatoes grown in sand and watered with nutrient. The aeration of the solution itself was of no importance for the growth of the tomato plants as soon as roots had developed in the basket. In some experiments it was even found that aeration decreased the growth rate in direct proportion to the amount of air passed through the solution.

Many sets of observations were made which must be omitted from this condensed account, including variation of environment and investigations of sugar content, auxin content, and osmotic concentration of the cell sap. Went notes that the root system in some solid, well-aerated medium is not essential for growth. Even when the whole root system is completely submerged in nutrient solution growth takes place, although in his experiments at a decreased rate. If the iron content of the nutrient solution is sufficiently high (10 to 100 times more than required when used in sub-irrigation) and when the pH is carefully kept adjusted, chlorosis does not necessarily develop in tomatoes which have their complete root system submerged in nutrient solutions. The important point, however, is that a very small proportion of all roots if outside the nutrient solution and in a healthy condition both offsets unfavourable pH or low iron content and greatly increases the growth rate. Even roots which have developed in the saturated atmosphere above a nutrient solution can perform this function.

The experiments showed that although the roots in the solid medium were able to take up water, the bulk of the water uptake occurred by the roots in nutrient solution. The roots outside the nutrient solution had practically no salt uptake, and when in haydite, silica gravel or sand could not take up organic materials. Yet they caused increased growth. Went concludes from these and earlier experiments of his own that their effect can only be due to internal secretion of a factor required for satisfactory top growth—a factor which he has already tentatively named caulocaline. In his own words: "If we piece all present knowledge together, we can conclude: Roots supply a factor (or factors) to the growing region of the shoot, indispensable for stem growth, and for convenience sake named caulocaline. In many plants this caulocaline is formed only in roots surrounded by moist air. It travels upward in the stem, apparently under the influence of auxin, through the living elements of the vascular bundles and has not been extracted in large quantities as yet."

Went then briefly discusses how his hypothesis may help to explain some well-known phenomena, and it is the suggestions advanced in this section that are of particular interest to the practical grower of plants. In the first place, he reminds the reader that various plants differ enormously as far as the air requirements round their roots is concerned. Many, such as rice, can grow with all of their roots submerged; but others, like tomato, must have part of their root system in contact with air to produce maximal growth. "This excessive aeration of the root crown is *not* required because otherwise no salts and water can be taken up; the oxygen requirement of the roots for salt absorption is much less than that for increasing the growth rate of the stems and for preventing the type of chlorosis described above."

Went goes on: "Many plants require a very light and loose top soil. If the upper soil layers are allowed to pack closely together, growth in these plants is stunted. Although in most plants the roots, especially those taking up water and salts, are located deep down in the closely packed soil, still a superficial cultivation of the soil around such a plant will decrease growth if the superficial roots have been injured. This must be due to the necessity of the root crown for growth, because this cultivation does not appreciably change the conditions around the absorbing roots which are in the main below the cultivated portion of the soil."

Finally, Went has some interesting remarks on the recently much discussed technique of "hydroponics," or growing of plants in water cultures. He points out that for 80 years plants have been grown with their roots immersed in nutrient solutions, and in the presence of all necessary inorganic elements satisfactory, although often slow growth was obtained. Proper aeration of the nutrient solution greatly increased growth in many plants. In some modern techniques used on a commercial scale the plants are supported about the nutrient solution in a seed bed containing some porous material, organic or inorganic, and this method is an improvement over the regular water-culture technique. Went concludes: "We thus reach the conclusion that the essential improvement of hydroponics over the old water culture method is to divide the functions of the root system: one root system takes up water and salts; the other, in the seed bed or between solution and seed bed, supplies caulocaline. And this is essentially the same division of labour as we encounter in most trees and perennials. They also develop a long fibrous feeding root system, which penetrates deep into the soil, and in addition they have a root crown which is well aerated, but due to its position, cannot well serve for water and salt uptake."

It appears to the reviewer that acceptance of Went's explanation of his own observations must involve for many agriculturists and horticulturists a rather drastic revision of their ideas about root systems, and in particular about "feeding" roots. It has always been difficult to reconcile in one's mind the obvious benefits of good soil aeration in the top layers with the excellent growth of many trees that so far as can be judged must be "feeding" at considerable depths where aeration cannot be abundant. Went's work suggests that a small proportion of well-aerated roots is sufficient, and that these need not necessarily be the feeding roots.

The suggestions afford a plausible harmonisation of apparently conflicting observations, and therefore merit very serious attention and critical study. It is for that reason that attention is called to them here.

They should not be applied too sweepingly without that critical study, bearing in mind that they are based mainly on the behaviour of the tomato plant and that their wider implication is as yet a matter of inference. Went writes of "a long fibrous feeding root system, which penetrates deep into the soil." This may not be true of some of our important tropical trees and shrubs. To take only one example, it now appears very important to determine the main function of the abundant fibrous roots produced near the soil surface by the cacao tree. These have been called "feeding" roots, and no doubt they do "feed", but that may not be their essential significance.

E. E. C.

CANE AGRICULTURE IN CUBA

A paper* bearing on certain physiological aspects of sugar cane by C. E. Beauchamp and J. E. Alvarino, discusses the possible relationship between the mineral composition of the leaves of different varieties of sugar cane and the efficiency of their mineral nutrition. Under present conditions the commercial value of a variety depends primarily on productive capacity and, secondly, on immunity from the more important diseases. Productive capacity is rather a vague term and, as here used, is the balance resulting from the interplay of the intrinsic potentialities of the variety and the environmental factors. The latter, in as far as they are dependent on climate are largely uncontrollable by man; in as far as they concern soil conditions, man can exercise a considerable degree of control. But the exercise of this control is costly and it is desirable, therefore, to determine that variety which can best utilize for the production of sugar the available conditions with the minimum of alteration. As all planters recognize, different varieties exhibit different responses to the same soil conditions in as far as productive capacity, measured as yield, is concerned. That is the resultant to the impact of a number of factors covered by the term soil conditions. But, in recent years, emphasis has come to be laid on fertilization as the major weapon in altering soil conditions and thus it comes about that interest centres on such differences as may be found to occur between varieties in their nutrient requirements. The problem may be stated thus: does high productive capacity in any variety depend on its power to absorb the essential mineral salts or on its power to make effective use of such mineral salts as it absorbs? That problem could, perhaps, be solved by field fertility trials but the work would be laborious. A short cut is desirable and that is the object of the work described.

Much labour in the past has been devoted to discovering some measure in the plant which will indicate the mineral deficiencies of the soil on which it is grown and the most promising yet discovered lies in the analysis of the leaf. That is the method here adopted. The varieties studied were seven: M 28, POJ.2878, POJ.2883, POJ.2714, POJ.2727, Co. 213, and Cristalina. The leaves selected were the fifth and sixth from the three-month-old ratoon crop. After chopping and drying, these were analysed for nitrogen, phosphorus, potash, lime and magnesia. As a measure of growth, the height of the stool from soil surface to the ultimate ligule at eight months was taken. From the crude analytical data thus obtained two factors are calculated; a quantitative one, *the intensity of nutrition*, being the sum of the percentages of nitrogen, phosphorus and potash, and a qualitative one, *the N.P.K. unit*, being the ratio of these three elements after conversion of the crude percentages to milligram equivalents and calculations of the percentage of each in the total.

The crude figures show wide and significant differences in the mineral composition of the varieties studied. Thus, the per cent. nitrogen ranges between 3.25 in POJ.2714 and 1.26 in Co.213; phosphorus from 1.10 in M.28 to 0.28 in Cristalina; potash from 3.72 in M.28 to 1.71 in Co.213; lime from 3.36 in POJ.2714 to 1.51 in M.28; magnesia from 1.48 in POJ.2714 to 0.66 in Cristalina. On the basis of nitrogen absorption the seven varieties fall into two groups, a high group composed of POJ.2714 (3.25), M.28 (2.49), POJ.2878 (2.40) and POJ.2883 (2.17), and a low group composed of POJ.2727 (1.54), Cristalina (1.47) and Co. 213 (1.26). The same result appears when the intensity of nutrition figures are considered; here the range is from POJ.2714 (7.63) and M.28 (7.13) to Cristalina (5.30) and Co. 213 (3.38).

Consideration of the development measured as average total length of cane per stool (in inches) shows Co.213 leading (3,722), followed by POJ. 2727 (2,216), POJ. 2878 (1,235), M.28 (1,207), POJ.2883 (1,109), POJ.2714 (1,035) and Cristalina (710). When the N.P.K. unit is considered, it is found that the proportion of the minerals in Co.213, M.28, POJ.2883 and POJ.2878 is practically identical. Thus the three latter canes underwent a development of less than a third of that of Co. 213 in spite of an intensity of nutrition approximately double. POJ.2727, which stands second in the field development, falls into the second group when intensity of nutrition is the basis of comparison. It has a little more nitrogen than, the same phosphorus as, but double the amount of potash of Co.213. It

* See Proceedings of the fourteenth Annual Conference Asociacion de Tecnicos Azucareros de Cuba.

is suggested that, to match the latter variety in productive capacity, POJ.2727 may need a greater amount of nitrogen. POJ.2714 shows a greater intensity of nutrition than any of the other varieties tested but has the lowest proportion of potash, suggesting that it requires a higher proportion of potash to balance its mineral nutrition at the level of the others. That would lead to an even higher intensity of nutrition, indicating that the variety requires high potential fertility—a conclusion in agreement with field experience. Cristalina, while possessing an intensity of nutrition and an N.P.K. unit similar to POJ.2727, has a lower intensity of nutrition and an N.P.K. unit lower in nitrogen but higher in potash than M.28, POJ.2883 or POJ.2878. It has, too, the lowest percentage of phosphorus of all the varieties tested, and it is suggested that fertilizer applications may require to be adapted to make good the deficiency in absorbing capacity of these two elements.

The work offers also some information on the difficulties sometimes experienced in the clarification of the juices of certain varieties. M.28, POJ.2727, Cristalina and Co. 213 present no such difficulties, the remaining three do so under certain conditions. It is shown that, by taking the sum of the percentages of nitrogen, lime and magnesia, the seven varieties fall into two groups: low—Cristalina (4.48), Co.213 (4.57), POJ.2727 (4.65) and M.28 (4.74), and high—POJ.2878 (5.33), POJ.2883 (6. 1) and POJ.2714 (8.09). These are the same two groups as practical experience shows to be based on ease of clarification. These observations are suggestive but require to be confirmed by further investigation.

It has earlier been pointed out that the tendency is in the direction of using the plant as indicator of fertilizer requirements and the measure adopted by C. E. Beauchamp is the mineral composition of the alcoholic extract of certain leaves. The determination would be much simplified if the whole leaf could be used and the extraction eliminated. An investigation designed to test this point was described in a paper by this author. The basis of this experiment was a field of M.28 on Matanzas clay having 14 treatments (including a check). The sixth leaf, counting from below at 3.5 months after planting was taken, with 18 leaves forming the sample of each treatment. Treatment was the equivalent of 418 lb. fertilizer per acre in combinations of N4 and 8, P_2O_5 4, 8 and 12, K_2O 4, 8 and 12.

The figures obtained from the alcoholic extract repeat earlier experience. While nitrogen and phosphorus in the extract show no clear correlation with the fertilizer treatment, potash shows a marked correlation which appears in the figure for the intensity of nutrition. The leaf skeleton (*i.e.* the residue after alcoholic extraction) shows a variation in nitrogen percentage from 2.53 to 2.69, in phosphorus from 0.466 to 0.669 and in potash from 0.400 to 0.840. The range in the first two is small but in these, as well as in the wider range of the potash percentage, no correlation with fertilizer treatment is apparent. It follows that, since alcohol extracts only 16.97 per cent. (average) of the entire dry weight of the leaf, the figures for the entire leaf cannot have the same significance as the alcoholic extract in interpreting the fertility of the soil.

The same features characterize the N.P.K. unit. The dominance of the skeletal fraction in the matter of nitrogen—between 79.96 and 85.98 per cent. in the entire leaf as against 34.41 to 51.16 per cent. in the alcoholic extract—reduces the potash percentage from between 35.42 and 55.44 to between 9.92 and 14.49, a range in which the differences are barely significant. Entire leaf analysis is, thus, of little advantage except in the case of large differential treatments.—(*The International Sugar Journal*, Vol. XLIV, No. 519, p. 61.)

A MOISTURE INDEX FOR SUGAR CANE

As everybody knows, water is an essential factor in plant growth; when the soil is full of moisture all the tissues of the plant are turgid and growth is proceeding at the maximum rate permitted by the other factors in the environment; when the soil moisture has become depleted by evaporation and transpiration the plants lose water and approach a condition of wilting. If the supply of moisture is not immediately renewed by rain or irrigation, the plants will suffer damage. It is therefore of importance to be able to recognize the point where the moisture supply of the plants has become dangerously low. This might be done by taking a sample of a number of whole plants and determining their moisture content, but it will be simpler and easier if the analysis can be performed on a selected part of the plant, the moisture content of which correlates with the moisture content of the whole plant. H. F. Clements and T. Kubota (*Hawaiian Planters Record*, vol. 46, No. 1) have found that the sheaths of the elongating sugar cane leaves, when analysed, are a suitable moisture index. Their method is to take samples of sheaths at intervals of one month throughout the growing period and dry them at 90°C.; the loss of weight represents the moisture content. From the data collected on variety 31-1389 it appears that the range in moisture level of the sheaths associated with rapid growth is between 83.5 and 85.5 per cent. If over 85.5, the cane is overwatered; curtailment of growth begins when the moisture content of the sheaths has fallen to 82.5 per cent., and the more the moisture index drops, the slower the growth. Hence the moisture index, determined throughout the growing season, gives a running picture of the condition of the crop and a guide for irrigation.—(*Sugar*, Vol. 38, No. 3, p. 35,1943.)

STUDIES ON AERATION AND WATER SUPPLY IN SOME CACAO SOILS OF TRINIDAD

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Introduction

During the course of our ecological studies of cacao in Trinidad, special attention has been given to the periodic determination of gross soil moisture within various experimental areas that have been established in different parts of the Island. At the beginning of the field work early in 1931, two contrasted plots were laid down by Mr. J. A. McDonald (Chemist for Cacao Research) at Torrecilla Estate, Arima, ("Good Plot") and at Las Hermanas Estate, San Rafael ("Bad Plot"). Soil moisture contents at three depths, namely, 0-6, 6-12 and 12-24 inches, were determined fortnightly in these two plots without break up to the end of June, 1934 (1). The records thus cover three wet and three dry seasons which differed considerably in intensity, so that they represent a wide range of soil conditions.

In June, 1939, three rows of five cacao trees each were selected for special observation by Dr. E. C. Humphries (Chemist for Cacao Research) at River Estate, the Government Cacao Experiment Station in Trinidad. Soil moisture contents at two depths, namely, 0-6 and 6-12 inches, were here determined weekly for each row up to the beginning of June, 1942, with only a 5 weeks' break in March-April, 1940. During April, 1940, four other groups of trees were similarly selected by Dr. Humphries for observation within the Botany Plots at the College, and soil moisture contents at the same two depths were here also determined weekly until the end of June, 1941. Finally, in July, 1940, three small cacao plots were established for a similar purpose at La Reconnaissance Estate situated in the Lopinot Valley in the Northern Range, and soil moisture contents at two depths were determined weekly up to the end of June, 1942.

A considerable mass of soil moisture data has thus accumulated and is now available for interpretation in the light of the preliminary investigations completed by Dr. H. Vine and Mr. H. A. Thompson (former Post-Graduate Students at the College) which have been described elsewhere by the writer (2).

Description of Sites and Soils

The two original contrasted plots laid down in 1931 comprise respectively coarse sandy soil (Torrecilla) and compact silty-clay soil (Las Hermanas).

(1) *Torrecilla Estate:* The plot at this site occurs on the first alluvial terrace (upper vega) of the Arima River near its debouchement from the Northern Range. The soil is an orange-coloured quartzose and schistose sand, and belongs to the *River Fine Sand* soil-type (3).

The structure is crumby in the surface humic layer but single-grained and compact lower down. Gravel is abundant below the 42-inch depth. The main features of the soil as revealed by laboratory examination are given in Table I. The reaction is acid, becoming highly acid below the 12-inch depth. Organic matter content is medium in the surface 6-inch layer, but falls rapidly below. Carbon-nitrogen ratio is satisfactory in the surface layer and drops to small values below the 12-inch depth. Phosphate and potash status is satisfactory. The cacao trees are mostly very old, but the yields are still fairly good being about 550 lb. of dry cacao per acre.

(2) *Las Hermanas Estate* The plot at this site occurs on the low-lying left bank of the Tumpuna River, a tributary of the Caroni River flowing across the Northern Plain of Trinidad. The soil is a heavy yellow clay belonging to the *Sangre Grande Clay-Silt* soil-type (3).

The structure is crumby in the surface one-inch layer, but compact below. The profile shows a mottled grey "gley" layer below the 20-inch depth, indicating frequent water-logging. The reaction (Table I) is highly acid, even in the surface 6-inch layer. The organic matter content of this layer is medium-low, but it is mostly confined to the top one-inch which is covered by a mat of fine roots and leaves ("*biche*"). Carbon-nitrogen ratio is low, suggesting either an insufficient supply of litter or loss of surface soil by erosion (4), or a rather nitrogenous type of humus. The land is liable to occasional floods during the rainy season. Phosphate and potash status is low and inadequate. Yields of cacao are poor, namely, only about 165 lb. dry cacao per acre.

The three newer plots, laid down at other cacao estates during 1939 and 1940, are described below.

(3) *College Botany Plots:* The soil here is a variable orange-coloured sand belonging to the *Maracas Sand* soil-type (3). It is not unlike the Torrecilla soil though it is not alluvial but detrital in origin. The site comprises two sections, the more southerly (3A: Table I) being less sandy and gravelly but much more acid than the other which has been limed.

The organic matter content of this soil is medium-low and the carbon-nitrogen ratio is unsatisfactory. The nutrient status is inadequate and the yields are probably only medium (say, 350 lb. acre), though the trees are still young.

(4) *River Estate:* This site occurs in Field 25 (Propagation Field), comprising uniform sandy alluvium of the Blue Basin River. It is divided into three 5-tree strips. The soil is a tawny-brown sand, belonging to the *River Fine Sand* soil-type (3).

The structure is crumby in the surface 3-inch layer but single-grained and compact below. The reaction is nearly neutral in the top six inches and only slightly acid below. Organic matter is medium in amount and carbon-nitrogen ratio is fairly satisfactory. The nutrient status is medium, with a tendency to potash shortage. Yields are fairly high, about 500 lb. per acre.

(5) *La Reconnaissance Estate:* This site occupies a small alluvial flat in a narrow steep-sided valley. The soil is a dark yellow-brown sand belonging to the *River Fine Sand* soil-type (3).

The structure is crumby in the top one-inch layer but compact below. The reaction throughout is slightly acid. Organic matter is variable but only medium in amount, and carbon-nitrogen ratio is unsatisfactory, though variable. The nutrient status is fair, and yields are fairly high, about the same as the Torrecilla soil, though the trees are old.

Experimental Procedure

(1) *Determination of gross soil moisture content:* A carpenter's one-inch screw auger was used for procuring soil samples at ten equally-spaced spots within each area. The spot samples were collected in enamelled pails provided with lids. They were well mixed and sub-sampled into cigarette tins whose lids were then sealed with insulating tape. The sub-samples were taken to the laboratory for weighing, oven-drying and re-weighing. Moisture contents are expressed as percentages on oven-dry weight of soil.

(2) *Determination of physical and chemical constants:* For the purpose of soil description, shallow profile pits were dug at each site and soil samples were collected with a trowel in layers, 0-3, 3-6, 6-12, 12-18 and 18-24 inches in depth. The samples were air-dried in the laboratory and analysed by the routine quantitative methods customarily employed at the College. The results obtained are set out in Table I.

(3) *Determination of porosity:* A special sampling tube was used for collecting representative constant-volume samples of soil with as little disturbance as possible, from five layers, as above. The sampler was the same as that used by Dr. H. Vine and Mr. H. A. Thompson in their preliminary investigations above-mentioned (2). It consists of a sharp-edged, deeply-slotted brass cylinder, 2 inches long by $1\frac{3}{4}$ inches internal diameter (volume 84.5 cc.), fixed by screws into a strong brass bridge or boss attached to a stout brass rod, 14 inches long by $\frac{3}{4}$ inch diameter. The sampling tube is placed horizontally against the middle part of the layer of soil to be sampled in a 3-foot section exposed in a pit dug for the purpose. It is then gently forced in by hand pressure or by taps with a wooden mallet until it has penetrated fully. The tube is previously dipped in water to lubricate it when sampling stiff dry soil, and care is taken not to shear the soil by turning the sampler too far. The core is finally removed by twisting it off at the base and withdrawing the tube. It is then trimmed off with a sharp table-knife while still in the sampling tube, so that its final volume is that of the internal cylindrical space. The core is removed with a jack-knife or extruded by pressure of the thumb into a numbered cigarette tin, which is then covered with a lid and sealed with insulating tape. At least two separate core samples are procured at widely separated spots in each layer, and often two or more pits are sampled in each plot or experimental area.

(*a*) *Total pore-space:* In the laboratory, the tins and their contents are weighed, and the soil dried in the oven and weighed again. From volume and weight of dry solid matter, the *apparent specific gravity* (D_2) of the soil is calculated. A powdered representative sample of the oven-dry soil is next weighed and put into a dry 100 cc. narrow-necked glass measuring flask, and alcohol is added up to the mark from a burette. The volume of the empty flask is also measured by filling with alcohol from a burette, and the volume of oven-dry soil is thus ascertained by difference. From the volume and weight of oven-dry soil, the *true specific gravity* (D_1) of the soil substance is deduced. Finally, *total pore-space* (volume per cent.) is calculated from the formula, $S = 100 \frac{D_1 - D_2}{D_1}$

(*b*) "*Capillary*" *pore-space* is estimated by determining the sticky point moisture content and the content of coarse and fine sand (i.e. 2.0-0.02 mm. particle diameter) on corresponding samples collected from the profile at the time when the constant-volume soil-cores are being procured. Index of texture value (sticky point *minus* one-fifth total sand content) is calculated from these data for each soil sample. The index of texture value is taken as an approximate measure of "total bound water" or "colloidally-held water", and hence identified with the so-called "capillary" pore-space water (5). Its volume per cent. is determined by multiplying the index of texture value by the apparent specific gravity (D_2).

(*c*) "*Non-capillary*" *pore-space* is obtained by subtracting capillary pore-space from total pore-space.

The results obtained for the three porosity characteristics are brought together in Table II, in which the values for each of the three depths, 0-6, 6-12 and 12-24 inches have been derived by averaging the data.

NOTE.—Great significance is attached to the accuracy of the value for apparent specific gravity (D_2), because on it depends the accuracy

Table I

Laboratory Data for Cacao Plot Soils

1	2	3	4	5	6	7	8	9	10	11
Site	Sampling depth (ins.)	Sand content (2.0-0.02 mm.) %	Index of texture	Reaction (normal) (pH)	Total organic matter %	Total nitrogen %	C/N ratio	Avail. phosphate (P_2O_5) (p.p.m.)	Avail. potash (K_2O) (p.p.m.)	Approximate yielding capacity (lb. dry cacao/ac.)
(1) Torrecilla Estate, Arima (*River Fine-Sand* soil-type)										
Routine plot	0- 6	60	15	6.3	3.1	0.17	10.0	142	109	550
	6-12	62	11	5.6	1.0	0.08	7.1	119	102	
	12-24	67	10	5.0	0.6	0.07	4.9	113	88	
(2) Las Hermanas Estate, San Rafael (*Sangre Grande Clay-Silt* soil-type)										
Routine plot ...	0- 6	15	48	5.7	2.6	0.20	7.5	20	72	165
	6-12	19	40	4.9	0.9	0.12	4.3	12	75	
	12-24	20	42	4.8	0.8	0.11	4.2	11	58	
(3) College Botany Plots, St. Augustine (*Maracas Sand* soil-type)										
(A) Trees 1-6 ...	0- 6	48	20	4.4	2.0	0.15	7.6	20	80	350
(B) Trees 1-6 ...	6-12	47	20	4.1	1.7	0.14	6.9	13	—	
(D) Trees 1-6 ...	12-24	52	15	4.6	0.8	0.09	5.1	4	—	
(C) Trees 7-9 ...	0- 6	57	12	7.5	1.9	0.12	9.1	160	43	
	6-12	54	14	7.4	1.1	0.10	5.7	20	—	
	12-24	57	12	7.2	0.7	0.09	4.4	10	—	
(4) River Estate, Diego Martin (*River Fine-Sand* soil-type)										
(A) Trees 892-896 ...	0- 6	55	16	6.6	2.5	0.16	9.0	58	91	500
	6-12	40	25	7.1	2.1	0.15	8.0	48	—	
	12-24	39	25	7.0	1.4	0.12	6.7	24	—	
(B) Trees 318-322 ...	0- 6	52	17	7.0	3.2	0.18	10.2	76	83	
	6-12	40	25	6.9	1.8	0.14	7.4	36	—	
	12-24	42	23	6.8	1.2	0.10	6.9	19	—	
(C) Trees 31-35 ...	0- 6	50	20	7.0	3.2	0.19	9.6	63	97	
	6-12	52	19	7.1	1.8	0.13	7.9	19	—	
	12-24	52	18	6.9	1.1	0.10	6.3	15	—	
(5) La Reconnaissance Estate, Lopinot (*River Fine-Sand* soil-type)										
New plot	0- 6	56	21	6.1	2.5	0.17	8.4	60	85	560
	6-12	52	19	6.4	1.6	0.13	7.0	40	—	
	12-24	57	11	5.4	0.6	0.07	4.9	—	—	

of the values for percentage volumes of space occupied by water and air on each sampling occasion. Hence the final value accepted for this constant should be based on as many separate determinations as possible, and these preferably should be made when the soil is moist, since many soils crack and shrink as they dry.

A good check on the accuracy of the apparent specific gravity value is afforded by noting the highest value for gross soil moisture content from the full set of periodic values procured in an investigation and assuming that it represents repletion of the soil pore-spaces by water with complete displacement of air. When multiplied by the apparent specific gravity value, the product should be numerically equal to the total pore-space volume. The data contained in Table II have been checked by this procedure and found to be sufficiently concordant.

Table II

Porosity Characteristics of Cacao Plots Soils

1	2	3	4	5	6	7	8	9		10
				Pore-Space						
Site	Sampling depth (ins.)	Appar. sp. gr. (D2)	True sp. gr. (D1)	Total (vol. per cent)	Capillary (vol. per cent)	Non-capillary (vol. per cent)	Wilting coeff. (vol. per cent)	Period of sampling for soil moisture content (years)	(days)	Frequency of sampling (days)
(1) Torrecilla Estate, Arima (*River Fine Sand*)										
Routine plot	0- 6	1.036	2.44	57	16	41	9	1931-1934	Feb. 16-	14
	6-12	1.184	2.52	54	13	41	8		June 29	
	12-24	1.324	2.54	48	13	35	7			
(2) Las Hermanas Estate, San Rafael (*Sangre Grande Clay-Silt*)										
Routine plot ...	0- 6	1.030	2.63	61	50	11	28	1931-1934	Mar. 4-	14
	6-12	1.230	2.70	54	49	5	32		Sept. 17	
	12-24	1.250	2.68	53	53	0	30			
(3) College Botany Plots, St. Augustine (*Maracas Sand*)										
(A) Trees 4-6 ...	0- 6	1.090	2.61	58	26	32	13	1940-1941	Apr. 29-	7
	6-12	1.230	2.58	53	22	31	12		June 30	
	12-24	1.258	2.65	52	17	35	—			
(B) Trees 1-2 ...	0- 6	1.250	2.62	52	29	23	15	1940-1941	Apr. 29-	7
	6-12	1.350	2.66	50	25	25	15		June 30	
	12-24	1.539	2.72	43	25	18	—			
(C) Trees 7-9 ...	0- 6	1.390	2.54	45	24	21	14	1940-1941	Apr. 29-	7
	6-12	1.530	2.60	41	26	15	15		June 30	
	12-24	1.693	2.60	36	11	24	—			
(D) Tree 3 ...	0- 6	1.175	2.63	56	27	29	13	1940-1941	Apr. 29-	7
	6-12	1.480	2.66	45	29	16	15		June 30	
	12-24	1.600	2.71	41	21	20	—			
(4) River Estate, Diego Martin (*River Fine Sand*)										
(A) Trees 892-896	0- 6	1.380	2.65	48	22	26	15	1939-1940	June 7-	7
	6-12	1.420	2.65	47	20	27	13		Mar. 18	
	12-24	1.566	2.70	42	20	22	—	1940-1942	Apr. 30-	
									June 9	
(B) Trees 318-322	0- 6	1.420	2.63	45	24	21	15	1939-1940	June 7-	7
									Mar. 18	
	6-12	1.402	2.65	47	25	22	15	1940-1942	Apr. 30-	
	12-24	1.528	2.68	43	24	19	—		June 9-	
(C) Trees 31-35	0- 6	1.404	2.65	47	29	18	17	1939-1940	June 7-	7
	6-12	1.402	2.64	47	30	17	16		Mar. 18	
	12-24	1.458	2.65	45	27	18	—	1940-1942	Apr. 30-	
									June 9	
(5) La Reconnaissance Estate, Lopinot (*River Fine Sand*)										
New plot ...	0- 6	1.223	2.58	52	26	26	17	1940-1942	July 5-	7
	6-12	1.385	2.60	47	27	20	16		June 10	
	12-24	1.482	2.61	43	28	15	—			

(4) *Determination of wilting coefficient:* This constant is derived from the value for maximum water-retaining capacity measured by Hilgard's perforated cup method on representative soil samples taken at the selected depths at each site. The results are expressed as volume percentages obtained by multiplying by apparent specific gravity.

(5) *Determination of water-table level:* Iron pipes, 1½ inches internal diameter and 40 inches long, are sunk vertically into the ground. Each pipe has three rows of holes, and is furnished with a covering of wire gauze and perforated zinc sheet, and its end is pointed. Water levels in the pipes are periodically measured with a wooden ruler. The readings are corrected for the volume of water displaced by each unit length of the ruler.

(6) *Presentation of results:* (i) Gross soil moisture contents have been regularly determined, in some cases weekly, in others fortnightly, usually without a break. The total sampling period has ranged from 43 months to 10 months at the various sites and it has mostly embraced two wet and two dry seasons.

(ii) The largest area sampled has been one-half acre, at the Torrecilla and the Las Hermanas sites; at other sites, smaller plots or areas occupied by groups of two to five cacao trees, or by a single cacao tree, have been sampled.

(iii) In the case of the two original sites (Torrecilla and Las Hermanas), three depths have been sampled for soil moisture content, namely, 0-6, 6-12 and 12-24 inches; in other cases, only two depths, namely, 0-6 and 6-12 inches have been sampled. The data have been recorded as weight percentages of water.

(iv) From the recorded results, volume percentage of water and of air have been calculated, based on data for apparent specific gravity and total pore-space procured by special sampling at the different sites during the wet season of 1942 (*See* Table II).

(v) The values for free air-space have been plotted in graphs for each set of data. Some typical diagrams are here reproduced. On these graphs, horizontal lines have been drawn representing (*a*) the stage of soil moisture depletion when permanent wilting sets in (the wilting coefficient), and (*b*) the provisionally-accepted minimum value (12 per cent.) for air content below which root asphyxiation might be expected to occur.

(vi) The data contained in Tables III to VI and discussed in the sequel represent the *percentage number of cases* for each yearly period (one wet and one dry season), for each sampling depth at each sampling site, in which the volume of the free air-space lay between selected arbitrary limits, namely, 0-5, 6-10, 11-20, 21-30 and 31-40 per cent. of the volume of the whole soil at the times of sampling.

Discussion of Experimental Data

The range of data obtained in this detailed investigation enables comparisons to be made between the following sets of contrasted conditions over varying periods of time:—

(A) *Comparison of soil-types:* i.e. soils of widely differing texture and structure, (Torrecilla *v.* Las Hermanas: Table III and Fig.I).

(B) *Comparison of topographical environments:* i.e. soils of similar sandy texture occupying sites of widely-differing topography (College *v.* River *v.* La Reconnaissance: Table IV and Fig. 2).

(C) *Comparison of groups of trees:* i.e. soils supporting a single tree or groups of trees, (College and River: Table V and Figs. 3 and 4).

The three cases will be considered separately.

(A) A comparison of sites having soils of different texture and structure. Table III: Fig. I.

The data presented in this table and chart refer to the two original contrasted ecological cacao plots, namely, the "good" sandy soil plot at Torrecilla Estate, and the "bad" clay soil plot at Las Hermanas Estate. The figures cover a long period, comprising three wet seasons and three dry seasons during which soil moisture values at three depths were determined fortnightly. The rainfall for the three years varied considerably (*See* Table III). The wet season of the first period (June to December, 1931) was *relatively* dry at each site, and the dry season (January to May, 1932) was *relatively* wet. By contrast, the wet season of the third period (June to December, 1933) was relatively wet, and the dry season (January to May, 1934) was relatively dry. The wet and dry seasons of the second period (June to December, 1932, and January to May, 1933) were intermediate between these two. The effects of the differences in weather are strikingly manifest in the aeration figures presented in Table III, and are well brought out by the diagrams in Figure 1.

NOTE ON FIGURE 1:—Here the aeration and soil moisture data referring to the surface layer (0-6 inch) at the two contrasted plots are set out for the two annual periods which showed the greatest differences in rainfall. The bottom block-diagram represents the distribution of the rainfall as weekly means of 4-weeks' moving averages calculated from rain-gauge records at the two estates. The other diagrams show for each site the fluctuations of soil-water and soil-air, expressed as percentages of the total volume of soil. The shaded lower portions represent soil-water and this is sub-divided into "capillary" water (i.e., that firmly held or combined in the micro-pores and at the active colloidal surfaces) and "non-capillary" water (i.e., that occupying the macro-pores). The horizontal white lines across the capillary water compartments represent the wilting coefficient danger level, which is relatively low for the sandy soil but high for the clayey soil. The horizontal

Table III

Differences in Free Air-Space between two contrasted Cacao-Plot Soils for three consecutive growing seasons

June, 1931—May, 1934.

(Data based on 78 fortnightly determinations of soil moisture at each site)

Season	Sampling depths (ins.)	Free Air-Space (volume per cent) 0-5 Per cent	6-10 Per cent	11-20 Per cent	21-30 Per cent	31-40 Per cent
(1) Torrecilla Estate: Routine Plot						
Coarse sandy soil (Percentage number of cases)						
1931-32	0- 6	0	0	38	54	8
	6-12	0	0	12	84	4
	12-24	0	0	69	31	0
1932-33	0- 6	0	8	31	57	4
	6-12	0	0	27	73	0
	12-24	0	0	74	26	0
1933-34	0- 6	0	24	44	24	8
	6-12	0	4	12	76	8
	12-24	0	0	72	28	0
(2) Las Hermanas Estate: Routine Plot						
Compact clay soil (Percentage number of cases)						
1931-32	0- 6	27	27	31	15	0
	6-12	80	8	12	0	0
	12-24	80	16	4	0	0
1932-33	0- 6	42	16	38	4	0
	6-12	80	16	4	0	0
	12-24	88	12	0	0	0
1933-34	0- 6	57	8	35	0	0
	6-12	76	8	16	0	0
	12-24	80	16	4	0	0

	Rainfall	Wet Season (June-December)	Dry Season (January-May)	Total
1931-32	Torrecilla ...	64.6 inches	30.5 inches	95.1
	Las Hermanas ...	90.5 ,,	34.0 ,,	124.5
	Means ...	77.5 ,,	32.2 ,,	109.8
1932-33	Torrecilla ...	72.7 inches	20.1 inches	92.8
	Las Hermanas ...	76.8 ,,	23.5 ,,	100.3
	Means ...	74.7 ,,	21.8 ,,	96.5
1933-34	Torrecilla ...	90.9 inches	12.6 inches	102.5
	Las Hermanas ...	80.1 ,,	16.9 ,,	97.0
	Means ...	85.5 ,,	14.7 ,,	99.7

Note :—The Wet Season of 1931-32 was relatively dry, and the Dry Season relatively wet, but the Wet Season of 1933-34 was relatively very wet and the Dry Season exceptionally dry. The Wet and Dry Seasons of 1932-33 were intermediate between these extremes.

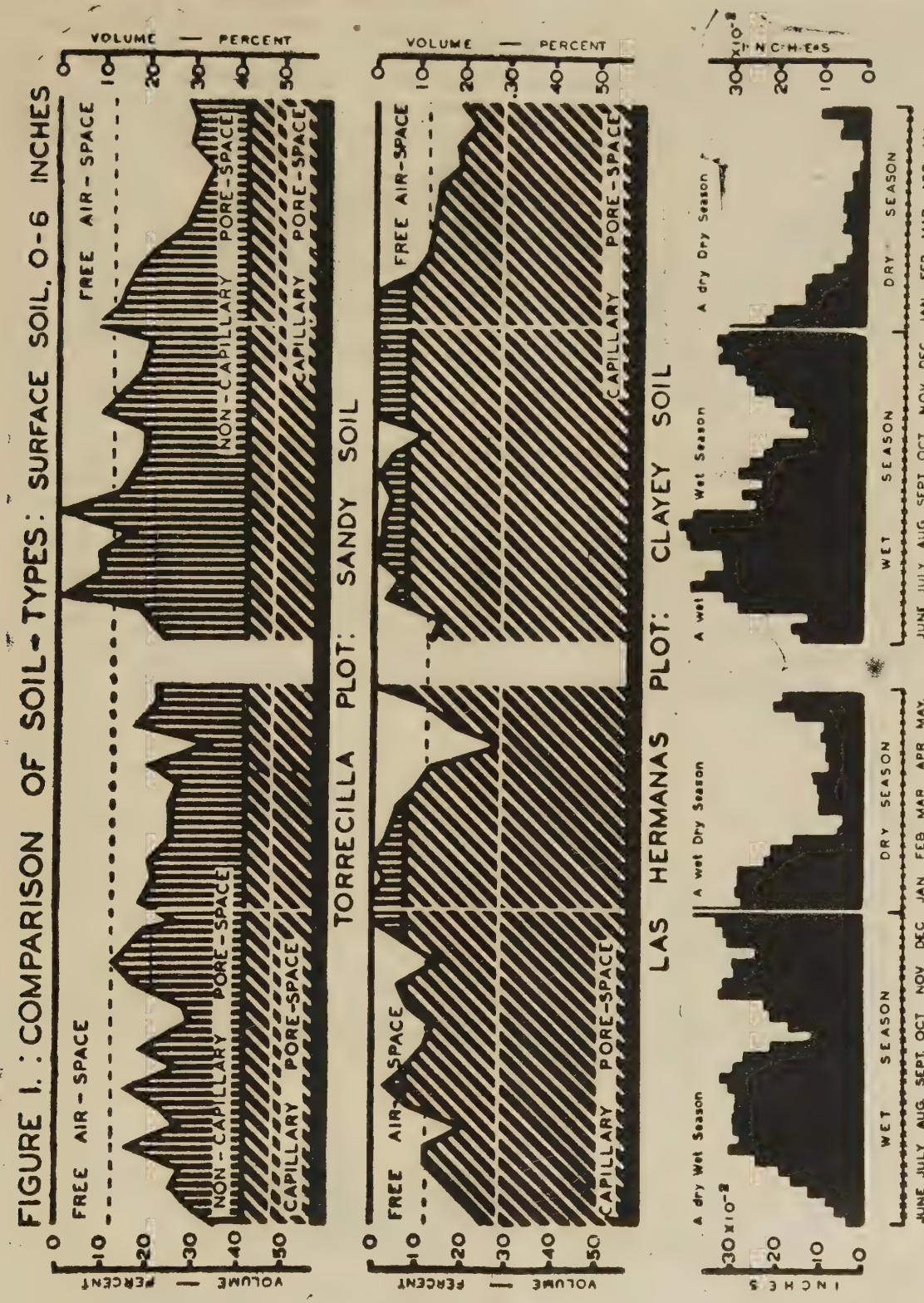
FIGURE I. : COMPARISON OF SOIL-TYPES: SURFACE SOIL, 0-6 INCHES
VOLUME — PERCENT
FREE AIR-SPACE
NON-CAPILLARY PORE-SPACE
CAPILLARY PORE-SPACE
TORRECILLA PLOT: SANDY SOIL
LAS HERMANAS PLOT: CLAYEY SOIL
A dry Wet Season
A wet Dry Season
A wet Wet Season
A dry Dry Season
WET SEASON
DRY SEASON
JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY
1931
1932
1933
1934
INCHES

black dotted lines across the free-air compartments at the 12 per cent. point represent the danger level of soil-gas which is likely to contain too much carbon-dioxide when the air-space volume is less than this amount (2). Hence the occupied region lying between these horizontal lines evaluates approximately the available water and air status, and may thus be regarded as a rough measure of "physical fitness" of the soil.

Fig. 1 clearly indicates the great superiority of the Torrecilla site in this respect. At this site, adequate amounts of soil-air and water were available together at all times of the year except perhaps during the wettest spell (July-August, 1933). At the other site, adequate amounts of soil-air and soil water were available together only during the early part of each wet season and the later part of each dry season, a total period of only about 6 months out of the 24 months covered by the diagrams. At this clay site also the soil dried out to the wilting point in late April, 1932, whereas at the sandy site, the soil moisture content lay well above the danger level throughout, and the non-capillary spaces were never devoid of water.

(1) It is apparent that, at the *Torrecilla site*, the volume of free air-space was never less than 10 per cent. at depths up to two feet, throughout the relatively dry first annual period, 1931-32. By contrast, throughout the relatively wet third annual period, 1933-34, the free air-space volume lay between 6 and 10 per cent. in the surface 6-inch layer on 24 per cent. of the weekly sampling occasions. This suggests that, during very rainy spells, the pore spaces of the surface soil at this site may temporarily fill with water, but the fact that the subsurface soil (6-12 inches) and the subsoil (12-24 inches) did not show correspondingly low values for free air-space implies that natural underdrainage here is very free.

(2) At the *Las Hermanas* site, conditions are entirely different. At this site the volume of free air-space in the surface 6-inch layer was less than 10 per cent. on more than 50 per cent. of the sampling occasions, and it was less than 10 per cent. at lower depths on more than 80 per cent. of the sampling occasions throughout each of the three annual periods. Evidently the pore-spaces of the Las Hermanas clay soil are occupied by water to the almost entire exclusion of air for the greater part of the year, particularly the layers below the 6-inch depth. This suggests that natural under-drainage here is very unsatisfactory, and that the air supply is highly inadequate for normal root activity. The soil appears to be nearly permanently water-logged below the 6-inch depth in all but the driest weather, and roots are therefore mostly confined to a shallow surface layer of soil. Actual measurements showed that the water-table at the Las Hermanas site was seldom lower than 15 inches from ground level during the wet season, whereas at the Torrecilla site it was never less than 36 inches.

(B) Comparison of sandy-soil sites having different topographical setting. Table IV: Fig. 2

The data contained in this table and diagram refer to the three sandy sites, namely, College, River and La Reconnaissance, whose soils display somewhat similar texture, structure and porosity, but the sites occupy different topographical environments. The comparable figures cover a full year, including one wet and one dry season, and refer to two sampling depths, namely, 0-6 and 6-12 inches. Soil moisture determinations were made weekly.

NOTE ON FIGURE 2:—The diagrams here concern solely the surface 6-inch layer at the three sandy sites, and cover only one typical annual period. The rainfall distribution diagram at the bottom shows the weekly means of 4-weeks' moving averages for the three sites combined.

The other diagrams are analogous to those in Figure 1, and indicate the great difference between the College site and the other two sites. At the College site, adequate soil-air was available throughout the whole year, but available soil moisture was very deficient over a 10-weeks' spell in February to May, 1941, during which the wilting point was actually reached. The River Estate and the La Reconnaissance sites appear to be similar to each other, at least in-so-far as the surface 6-inch layer of soil is concerned, but they show great differences in the lower soil layers, not depicted however in the figure though clearly shown in Table IV.

(1) The *College site* lies on gently-sloping open ground, one-half mile south of the Northern Range foothills. The nearest stream is half-a-mile distant. The substratum is sandy but contains sporadic and irregular lenses of gravel and boulders at various depths. The water-table level as a rule seldom rises to within 3-feet of the ground surface. The site is exposed to winds during the dry season, and is poorly protected because of its small area and its isolated position near the College Savanna.

(2) The *River Estate site* is located about 80 yards from a fairly large river and at a relatively high level above its normal surface. It is seldom flooded. The land is flat for a considerable distance in all directions. The substratum is sandy, and the water-table only reaches the 3-foot level during continuous rainy weather. A municipal pumping station is located about one-fifth of a mile away. The site is fairly well protected, except on the north side where a main road runs alongside, and the shade trees present a good canopy.

(3) The *La Reconnaissance site* is located a few yards from a small perennial stream which becomes greatly swollen during the wet season and occasionally overflows its banks and floods the plot. The land slopes steeply upwards on the side away from the river. The substratum is gravelly and the water-table during rainy weather

FIGURE 2: COMPARISON OF ENVIRONMENTS

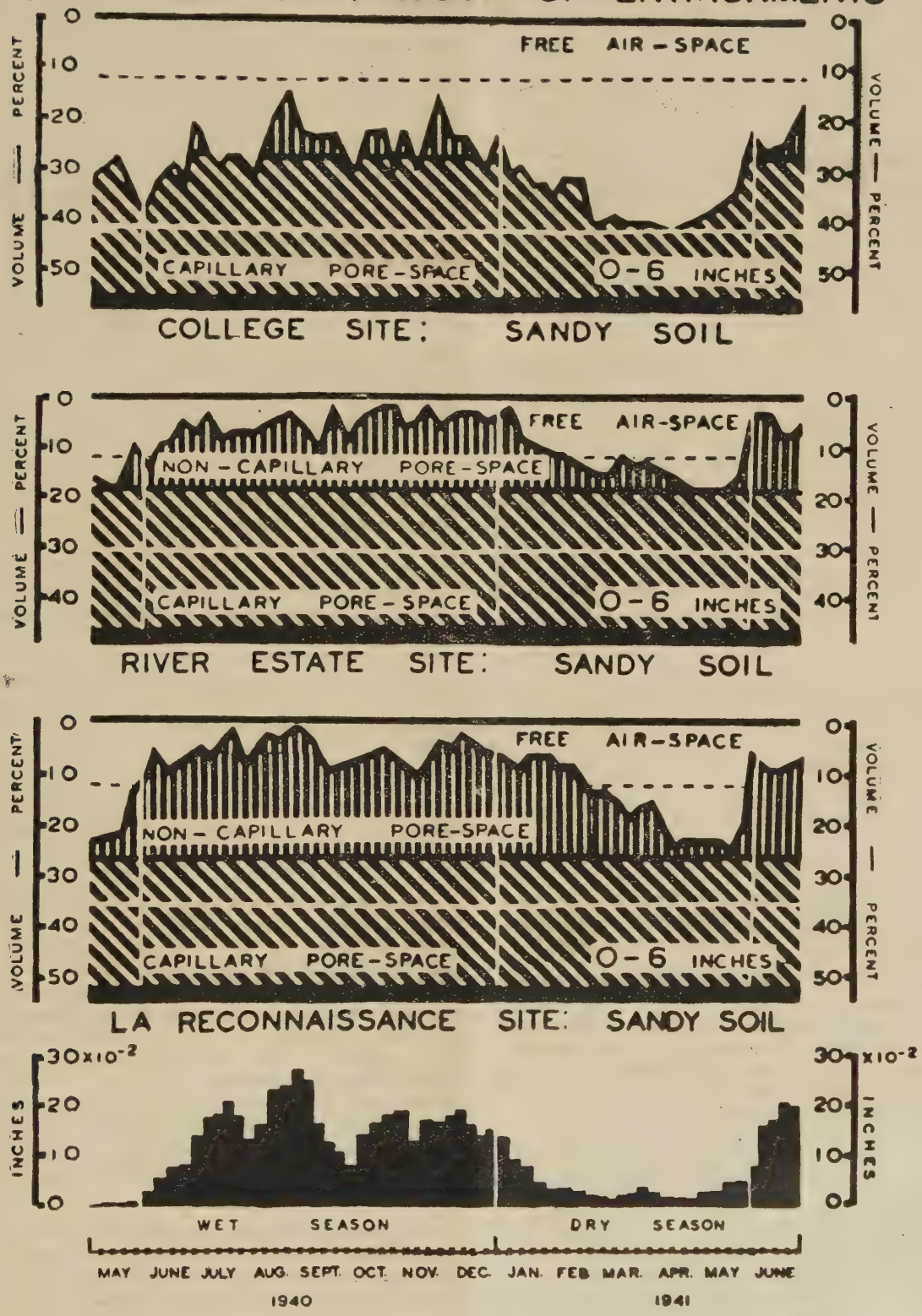

Table IV

Differences in free Air-Space between three topographically-different Sandy Cacao-Plot Soils for one growing season

June, 1940—May, 1941

(Data based on 52 weekly determinations of soil moisture at each site)

Sampling depths (inches)	Free Air-Space (volume per cent)				
	0-5 Per cent	6-10 Per cent	11-20 Per cent	21-30 Per cent	31-40 Per cent
	(3) College Botany Plots (Trees 1, 2 and Trees 4-6) (Percentage number of cases)				
0- 6	0	0	6	42	52
6-12	0	0	19	44	37
	(4) River Estate Plots (Trees 31-35 and Trees 318-322) (Percentage number of cases)				
0- 6	30	34	36	0	0
6-12	11	30	59	0	0
	(5) La Reconnaissance Estate Plot (New Plot) (Percentage number of cases)				
0- 6	19	48	33	0	0
6-12	35	35	30	0	0

Rainfall	Wet Season	Dry Season	Total
	(June-December)	(January-May)	
1940-41 College	48.5 inches	6.8 inches	55.3
River Estate	51.4 ,,	6.9 ,,	58.3
L. R. C. Estate	44.7 ,,	10.2 ,,	54.9
Means	48.2 inches	8.0 inches	56.2

frequently reaches within 3 feet of the land surface. The site is well protected on all sides, and shade trees effectively cover the cacao.

The order of increasing humidity at these three sites appears to be that given. The College site is the most subject to drought, as indicated by the fact that soil moisture contents generally fall to within 10 per cent. of the wilting coefficient value quite early in the dry season, that is, by the middle of January, whereas at the La Reconnaissance site, they do not fall so low until the middle of April. At the River Estate site, this degree of dryness is usually attained by the end of February. Furthermore, the dryness of the air under the cacao trees, as measured by Piche evaporimeters, is about 44 per cent. greater during the dry season at the College site than at the other two sites, which show nearly equal degrees of dryness. At the College site, leaf flushes often dry up and die towards the end of the dry season and the shedding of older leaves often completely denudes the trees of foliage.

The marked differences in environmental conditions between these three sandy-soil sites is clearly reflected in the degree of aeration of the soil throughout the year. In Table IV and Fig 2 it will be noted that on no occasion was the free air-space of the soil at the *College site* (at least down to the 12-inch level) less than 10 per cent. of the total soil volume, so that cacao roots penetrating to 12-inch depth or below are here never exposed to danger of asphyxiation. Indeed, only on about 50 per cent. of the total number of sampling occasions was the free air-space volume less than 30 per cent. of the soil volume.

By contrast, the soil down to the 6-inch depth at both the *River Estate* and the *La Reconnaissance sites* contained less than 10 per cent. of free air-space on more than 60 per cent. of the number of occasions when it was sampled, and never contained more than 20 per cent. of air-space on any occasion. The data also indicate that the aeration of the subsurface soil (6-12 inches) is

poorer at the La Reconnaissance site than at the River Estate site. Evidently the surface soil down to the 6-inch depth at the River Estate site tends to hold and retain water falling as heavy showers of rain, so that it is presumably more often temporarily deprived of air than its own subsurface soil, and more often than the surface soil at the La Reconnaissance site.

The differences thus clearly revealed by the aeration data for these three sandy sites are entirely compatible with the environmental circumstances; they demonstrate the value of the experimental procedure described, in that it provides reliable evidence of the specific needs at the three sites, as follows:—

(1) The *College* site appears to need much greater protection against drought during the dry season. This might be afforded by the provision of more overhead shade and side protection, though satisfactory water relations at this site might never be attained unless irrigation is practised during dry spells.

(2) The *River Estate* site seems to need greater surface drainage in order to remove excess of water during heavy rains that apparently cause frequent water-logging in the uppermost soil layer. This might be afforded by the provision of surface drains, which need only be shallow, since subsoil drainage at this site seems to be adequate. Reforming the beds so as to produce a camber might also prove beneficial. Compaction of the surface soil within the sampling area may have taken place to some extent through trampling by the observers during their frequent periodic visits to the plot.

In order to test this last possibility, compaction measurements were made in June, 1942, by means of a simple penetrometer, after a week of continuous heavy rainfall. The average value obtained was 43 strokes for the River Estate site as compared with only 20 strokes for the La Reconnaissance site which has been much less trampled.

(3) The *La Reconnaissance* site appears to suffer from inadequate under-drainage during the wet season, though it would be difficult, if not impossible, to rectify this condition because of the height of the river at that time of the year, which provides no outfall from the plots.

(C) Comparison of individual trees or groups of trees. Table V: Figs. 3 and 4.

In this table and these two charts are brought together aeration data for rows or groups of trees which have been periodically sampled at two of the sites described in the last section. The data reveal marked and unexpected variations in soil aeration within relatively short distances. The most contrasted cases are depicted in the diagrams, which are self-explanatory.

(1) The *College site* comprises four groups of trees, designated Trees 1-2, Tree 3, Trees 4-5 and Trees 7-9 respectively.

The first group of trees is the most southerly. The second consists of one tree only. The first three groups are close together and occupy positions only about 20 yards apart. The last group is situated north of and across the public road, immediately behind the College power-station, distant about 400 yards from the other tree-groups.

The soil at the different spots varies, not only in porosity (Table II), but also in physical and chemical features (Table I). The soil of the most northerly spot (Trees 7-9) is the most sandy but the most compact and contains the least non-capillary pore-space. Its reaction is markedly alkaline since the area has recently been limed; its potash status is lower than that of the soils at the other spots but its phosphate status is higher, features which may be attributed to differential manuring.

The aeration data (Table V and Figure 3) show greatest similarity between the environments of Trees 4-6 and Trees 1-2, in that the volume of free air-space never fell below 10 per cent. down to the full 12-inch depth. In contrast, the subsurface soils (6-12 inches) at the other two spots (Tree 3 and Trees 7-9) seem to be relatively poorly aerated, since they were nearly devoid of air on numerous weekly occasions when sampling was performed. Drainage tubes set up at these spots frequently showed water-table levels up to within 6-inches of the ground surface.

Aeration around the roots of Tree 3 appears to have been particularly bad, the volume of free air-space being less than 5 per cent. in the 6-12 inch layer on more than 50 per cent. of the sampling occasions, that is, during all or most of the wet season.

The demonstration by means of this method of experimentation of such marked differences between the soil environments of small contiguous areas or tree-sites reveals the true reality of soil heterogeneity. Environmental variations are indeed likely to be common in the cacao fields of Trinidad, especially where the soil-type is alluvial or detrital; the evidence may adequately explain marked differences in growth and yield of individual trees or groups of trees that are frequently observed by planters and employed by botanists when selecting high-bearing strains of cacao trees.

(2) The *River Estate site* comprises three rows of five trees, designated Row 31-35, Row 318-322 and Row 892-896 respectively. The rows run north to south; the first row is the most easterly and the first tree in each row is the most northerly. The soil within the area varies considerably, showing a definite fertility gradient from west to east across the rows (Table I); it becomes somewhat less sandy and more compact; its organic matter content increases and its nutrient status also improves slightly when traced in that direction. An increasing fertility trend, though not so regular, is shown also from south to north along the rows.

FIGURE 3. COMPARISON OF TREE GROUPS: COLLEGE SITE

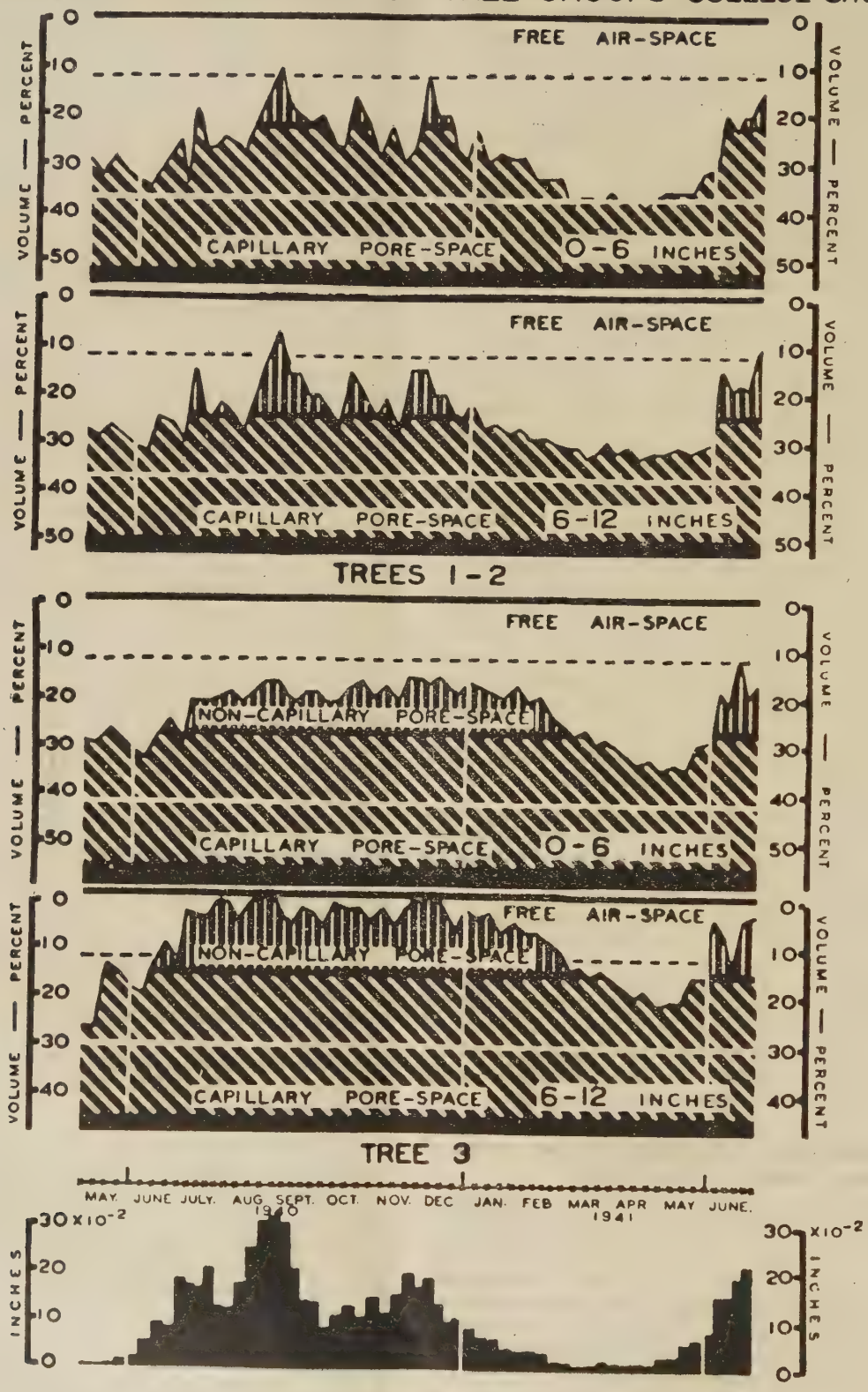

Table V

Differences in Free Air-Space between soils of Individual Groups of Cacao Trees occurring in the same plots

(Data based on 52 and 150 weekly determinations of soil moisture at two sites)

Site and Season	Sampling depths (ins.)	Free Air-Space (volume per cent) 0-5 Per cent	6-10 Per cent	11-20 Per cent	21-30 Per cent	31-40 Per cent
		(3) College Botany Plots (Percentage number of cases)				
1940-41						
(A) Trees 4-6	0- 6	0	0	0	46	54
	6-12	0	0	12	48	40
(B) Trees 1-2	0- 6	0	0	14	52	34
	6-12	0	0	24	52	24
(C) Trees 7-9	0- 6	0	17	46	21	16
	6-12	16	17	42	25	0
(D) Tree 3	0- 6	0	0	38	40	22
	6-12	52	16	32	0	0
		(4) River Estate Plots (Percentage number of cases)				
1939-40						
(A) Trees 892-896	0- 6	0	18	82	0	0
	6-12	0	25	69	6	0
(B) Trees 318-322	0- 6	12	46	42	0	0
	6-12	6	27	67	0	0
(C) Trees 31-35	0- 6	31	48	21	0	0
	6-12	10	50	40	0	0
1940-41						
(A) Trees 892-896	0- 6	0	16	84	0	0
	6-12	0	25	60	15	0
(B) Trees 318-322	0- 6	27	40	33	0	0
	6-12	6	33	61	0	0
(C) Trees 31-35	0- 6	34	27	39	0	0
	6-12	16	26	58	0	0
1941-42						
(A) Trees 892-896	0- 6	0	21	61	18	0
	6-12	0	25	68	7	0
(B) Trees 318-322	0- 6	50	25	25	0	0
	6-12	12	52	36	0	0
(C) Trees 31-35	0- 6	29	42	29	0	0
	6-12	14	54	32	0	0

Rainfall	Wet Season	Dry Season	Total
	(June-December)	(January-May)	
College (1940-41)...	48.5 inches	6.8 inches	55.3 ins.
River (1939-40)...	51.0 inches	7.0 inches	58.0 ins.
(1940-41)...	51.4 ,,	6.9 ,,	58.3 ,,
(1941-42)...	56.1 ,,	11.4 ,,	67.5 ,,

FIGURE 4 COMPARISON OF TREE-GROUPS: RIVER ESTATE

The aeration data (Table V and Figure 4) are arranged under three annual periods, namely, 1939-40, 1940-41 and 1941-42. The rainfall during the first two of these periods was nearly the same, i.e., around 51 inches in the wet season and 7 inches in the dry, but the third period was considerably wetter, both in the wet season (56 inches) and in the dry season (11½ inches). The mean wet season rainfall at River Estate (19 years' average) is 56 inches, and the mean dry season rainfall is 13 inches. Thus both the wet and particularly the dry seasons of 1939-40 and 1940-41 were unusually dry, but the period 1941-42 was nearly normal.

The values for free air-space volume for the soils of the three rows of trees show similar differences for each of the three annual periods. In every case the soil of Row 892-896 seems to have maintained the best aeration, for the air-space down to the 12-inch depth never fell below 5 per cent. of the total volume of the soil, whereas the soil of the other two rows frequently contained less than 5 per cent. air-space, particularly in the surface 6-inch layer. The soil of Row 318-322 seems to be somewhat better aerated than that of Row 31-35 which is apparently very poorly aerated. The free air-space of the surface 6-inch layer of soil of both these rows was apparently less than 10 per cent. on more than 60 per cent. of the number of occasions when the soil was sampled, but the subsurface soil (6-12 ins.) throughout was somewhat better aerated than the corresponding surface soil of each row. The effect of the greater wetness of the annual period 1941-42 is not particularly marked, except that, according to expectation, the subsurface soil (6-12 ins.) seems to have suffered lack of aeration more frequently during this period than during the two previous annual periods when the rainfall was smaller in amount.

As indicated by the laboratory data (Table I), the soil of Row 31-35 is the most fertile and that of Row 892-896 the least fertile of the three. On the other hand the soil of Row 892-896 has the greatest total pore-space and the greatest percentage volume of non-capillary pores (Table II), which doubtless account for its superior aeration mentioned above.

The cacao trees of this row are definitely larger than those in the other two rows, and their yielding capacity is greater. Thus, the average number of pods produced per tree per year over the four seasons 1938-1941 by Row 892-896 was 21 (giving 5 lb. of wet cacao), whereas the number produced by Row 318-322 was 19 (giving 4½ lb. of wet cacao), and by Row 31-35, only 17 (giving not quite 4½ lb. of wet cacao).* These results suggest that the superior structure and position of the soil of Row 892-896 as compared with the other two rows is mainly responsible for its higher bearing capacity and they apparently offset its somewhat inferior nutrient status. The trees of each of the three rows all belong to the same strain of cacao, being grown from clonal scions, so that differences in yielding capacity cannot be attributed to genetical factors.

*Information kindly supplied by Dr. E. C. Humphries.

Summary

(1) The proportionate amounts of water and air in the pore-spaces of certain kinds of sandy and clayey cacao soils common in Trinidad have been measured weekly or fortnightly during one to three growing seasons in order to determine the degrees of moistness or water-logging, and aeration. The following main results have been obtained.

(2) At a *sandy site* (Torrecilla), adequate amounts of soil-water and soil-air were available together at all times of the year, except during the very wettest periods. The content of soil moisture always lay well above the wilting co-efficient, and the non-capillary pore-spaces were never entirely devoid of water. Nevertheless, during very wet spells, the pore-spaces of the surface soil (0-6 ins.) temporarily filled with water with the complete exclusion of air, but those of the subsurface soil (6-12 ins.) did not necessarily fill at the same time, because of a marked percolation lag. The soil at this sandy site appears to suffer somewhat from inadequate surface drainage, though its natural under-drainage is very free.

(3) At a *clay site* (Las Hermanas), adequate amounts of soil-water and soil-air were available together only during the early part of the wet season and the later part of the dry season, a total time of only about one-quarter of the year. The soil dried out to the wilting point at this site near the end of the dry season. Thus the soil pore-spaces were occupied by water to the almost entire exclusion of air for the greater part of the year, especially below the 6-inch depth where the soil contains few or no non-capillary pore-spaces. This clay site appears to be badly under-drained, and aeration (except for a shallow surface layer) is probably nearly always inadequate for healthy root development.

(4) At three *sandy sites* (College, River and La Reconnaissance (L.R.C.)), occupying different topographical positions, comparatively large differences in water and air-supply were revealed. At the College site, fully adequate soil-air was available throughout the whole year, but soil moisture was very deficient during the greater part of the dry season and the wilting point was soon reached. At the River and the L.R.C. sites, the surface soil (0-6 ins.) was adequately supplied with air for only about half of the year, and was never really well aerated. At the River Estate site, the subsurface soil (6-12 ins.) was better

aerated than the surface soil, because of a marked percolation lag. At the L.R.C. site, however, the subsurface soil was water-logged for more than half of the year, and consequently poorly aerated. These differences are ascribed to differences in topographical features at the three sites. Suggestions are offered for their improvement.

(5) Within two of the sandy sites (College and River), large differences in water and air-supply were found to occur at the places where small groups or short rows of cacao trees are growing, thus demonstrating marked heterogeneity in the physical soil environment within relatively small areas. The differences are reflected in the growth and yielding capacity of the trees.

References

(1) An Environmental Study of the Cacao Tree; J. A. McDonald, First Annual Report on Cacao Research (for 1931), *I.C.T.A.*, 1932, pp. 29-38; Second Report (for 1932) *I.C.T.A.*, 1933, pp. ii-iv.

(2) Studies on Aeration of Cacao Soils in Trinidad; H. Vine, H. A. Thompson and F. Hardy; *Tropical Agriculture*, 1942, XIX, (I) pp. 175-180; (II) pp. 215-223; *ibid.* 1943, XX, (III) pp. 13-24; (IV) pp. 51-56.

(3) A Provisional Classification of the Soils of Trinidad; F. Hardy, *Tropical Agriculture*, 1940, XVII, pp. 153-158.

(4) Soil Erosion in Trinidad and Tobago; F. Hardy, *Tropical Agriculture*, 1942, XIX, pp. 29-35.

(5) Physical Properties that Affect Plant Nutrition; H. Vine, *Tropical Agriculture*, 1940, pp.106-109.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Phosphatic and Potash Resources in Russia

Russian geologists claim that the prospected phosphate rock deposits of the U.S.S.R. now exceed 60 per cent. of the world's resources. Near Kirovsk, in the Kola Peninsula, remarkable bodies of apatite, discovered in 1926, have recently been yielding more than 2 million tons of ore annually, with reserves for another millennium. The principal phosphorite deposits occur in European Russia, in the regions of Kirov (Phosphoritnaya) and Moscow (Egorjevsk), but an extensive and favourably situated field near Aktiubinsk in North-west Kazakhstan is being developed to supply agricultural fertilizers for western Soviet Asia.

The region of Solikamsk, on the western slopes of the Urals, has long been known for its brines and salt works, but it was only after deep boring commenced in 1925 that the remarkable deposits of potassium and magnesium salts (sylvinite and carnallite) and the enormous masses of rock salt were thoroughly investigated over an area of some 700 square miles. Production started in 1932 and within five years the annual output had arisen to more than 2 million tons of crude salts, and large quantities were being exported. Solikamsk reserves are claimed to represent about 80 per cent. of the world's resources, consisting of 15,000 million tons of potash salts, 18,000 million tons of magnesium salts, and scores of thousands of millions of tons of rock salt. Even the famous Stassfurt deposits of Germany are dwarfed. (*Nature*, 1942, No. 3810, p. 541.)

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Vitamin C Content of Guavas

According to investigations carried out at the Low Temperature Research Station, Capetown and reported in *Farming in South Africa*, 17, 1942, pp. 319-36—the guava is shown to possess a very high vitamin C content which, unlike that of orange juice, remains stable and potent after canning. In addition, the canned fruit is cheap and palatable. The vitamin C content depends greatly on the type of guava, and is said to be from 227 to 500 mgm. per 100 gm. of fruit, that of early season guavas being generally lower than that of late guavas. In South Africa guavas are not yet classified into varieties. Five main types were, however, distinguished. Vitamin C content does not appear to be greatly affected by degree of maturity. The richest source of the vitamin is the peel and the lowest the inner flesh. The inner flesh could indeed well be discarded. Very little vitamin C was lost in stewing or in jelly and in the case of jelly loss during storage at 98°F. was slow. In concentrated guava extract vitamin C is lost very rapidly. Loss was also rapid from powdered guava stored at tropical temperatures in sealed bottled.

* * *

Juice Quality Affected by Lodging of Cane

It is commonly said that the quality of the juice of canes which have lodged is poorer than that of canes that stand erect, but experimental proof of the fact is hard to find. An attempt to obtain an answer was made by planting cane in pots. After the canes had started growing, half the pots were tipped over so that the cane was in a horizontal position. In the course of further growth, the tops of these tipped-over canes turned upward so as eventually to form a right angle to the recumbent portion of the stalk. At harvest the recumbent and the horizontal portions of these canes were weighed and analyzed separately. In general, the yield of cane was less from the tipped-over stalks than from the canes that were left erect, and the overall sugar yield was around 11 per cent. less. A number of the pots in both variants were given an extra amount of nitrogen fertilizer, but the results did not show that extra nitrogen has anything to do with lodging.—(*Sugar* Vol. 38, No. 3, p. 36, 1943).